FORUM-AE COORDINATION ACTION

FP7 European coordination action ; GA 605506 ; 2013-2017

Emissions Mitigation Concepts

Paul Madden, Denise Ahrens (RR)
Olivier Penanhoat, Yoann Mery, Nicolas Tantot (Safran-AE)

ECATS 2nd Conference on Making Aviation Environmentally Sustainable and Climate Change Joint Workshop with FORUM-AE
Athens – 8th Nov. 2016

www.forum-ae.eu

Seventh Framework Programme
European Union funding
for research, technological development
and demonstration

CONTEXT: ACARE GOALS

ACARE Environmental Goals by 2050

- CO_2 emissions per passenger kilometre have been reduced by 75%, NO_x emissions by 90% and perceived noise by 65%, all relative to the year 2000.
- Aircraft movements are emission-free when taxiing.
- Air vehicles are designed and manufactured to be recyclable.
- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.
- Europe is at the forefront of atmospheric research and takes the lead in formulating a prioritised environmental action plan and establishes global environmental standards.

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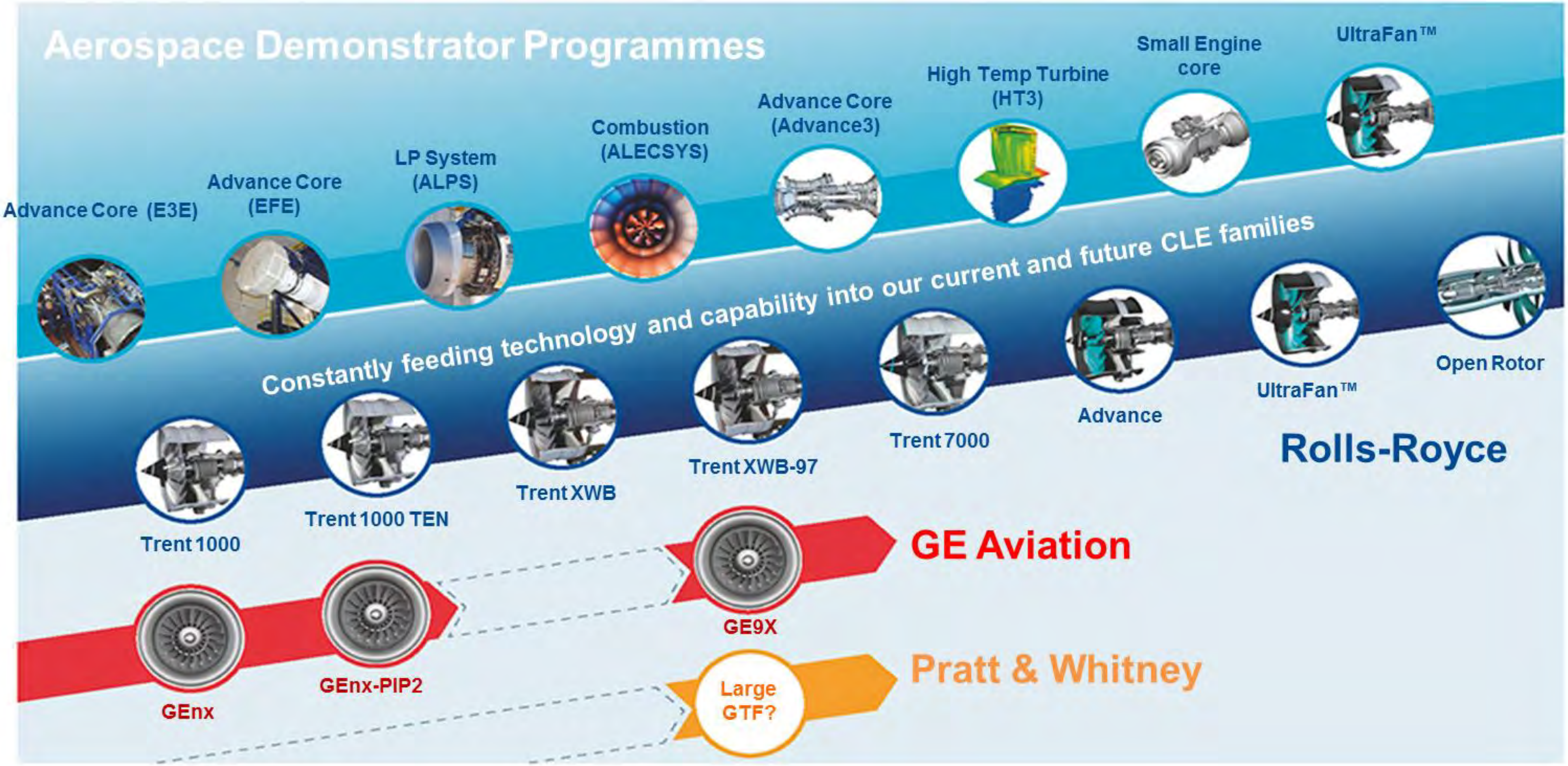
Rolls-Royce Engine Demonstrator Programmes



➔ **Continuous Effort on Technology to Reduce Fuel Burn and CO2**

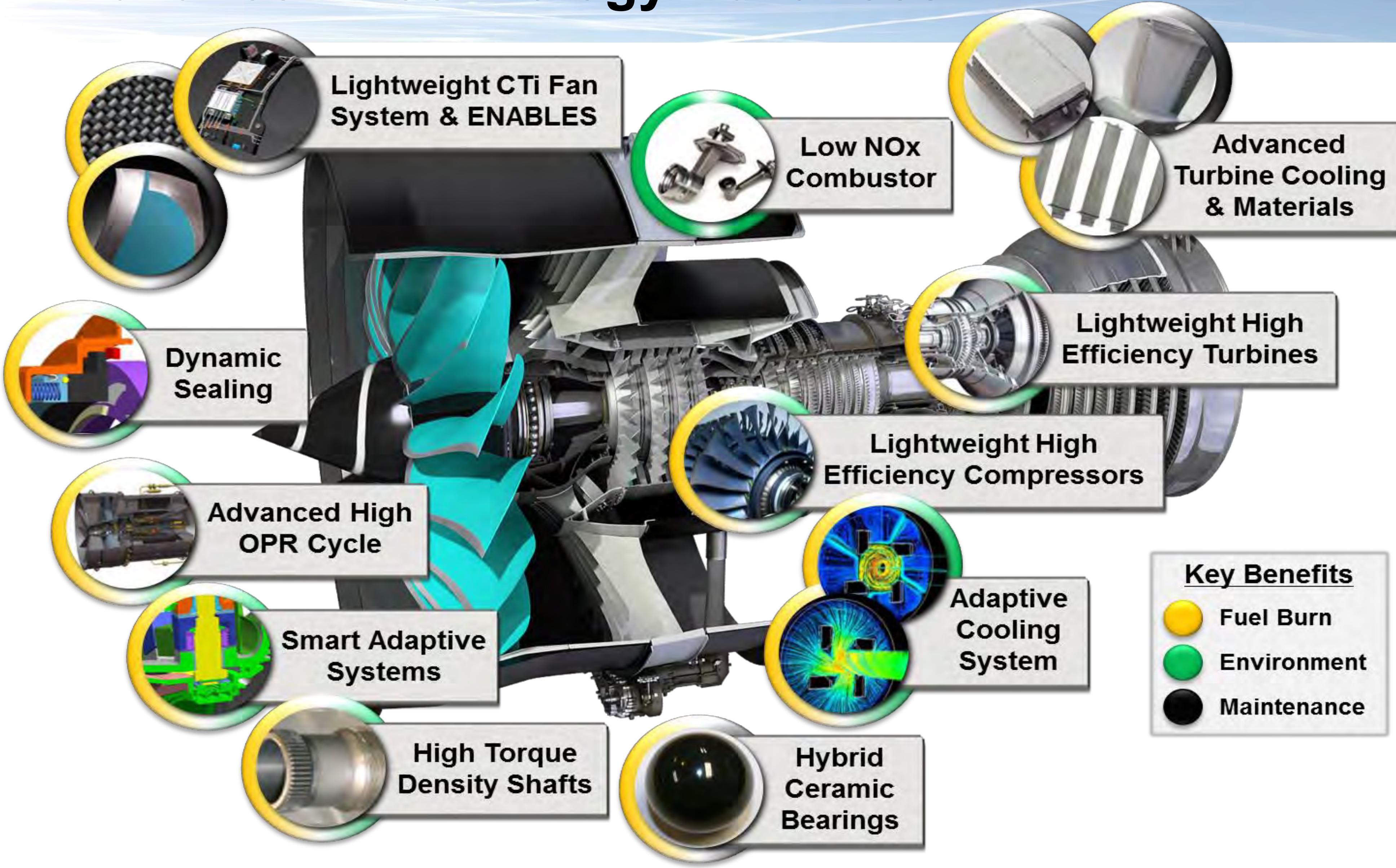
World-Leading Product Evolution

Technology EIS Readiness	2020+	2025+
Bypass Ratio	11+	15+
Overall Pressure Ratio	60+	70+
Efficiency relative to Trent 700	20%+	25%+

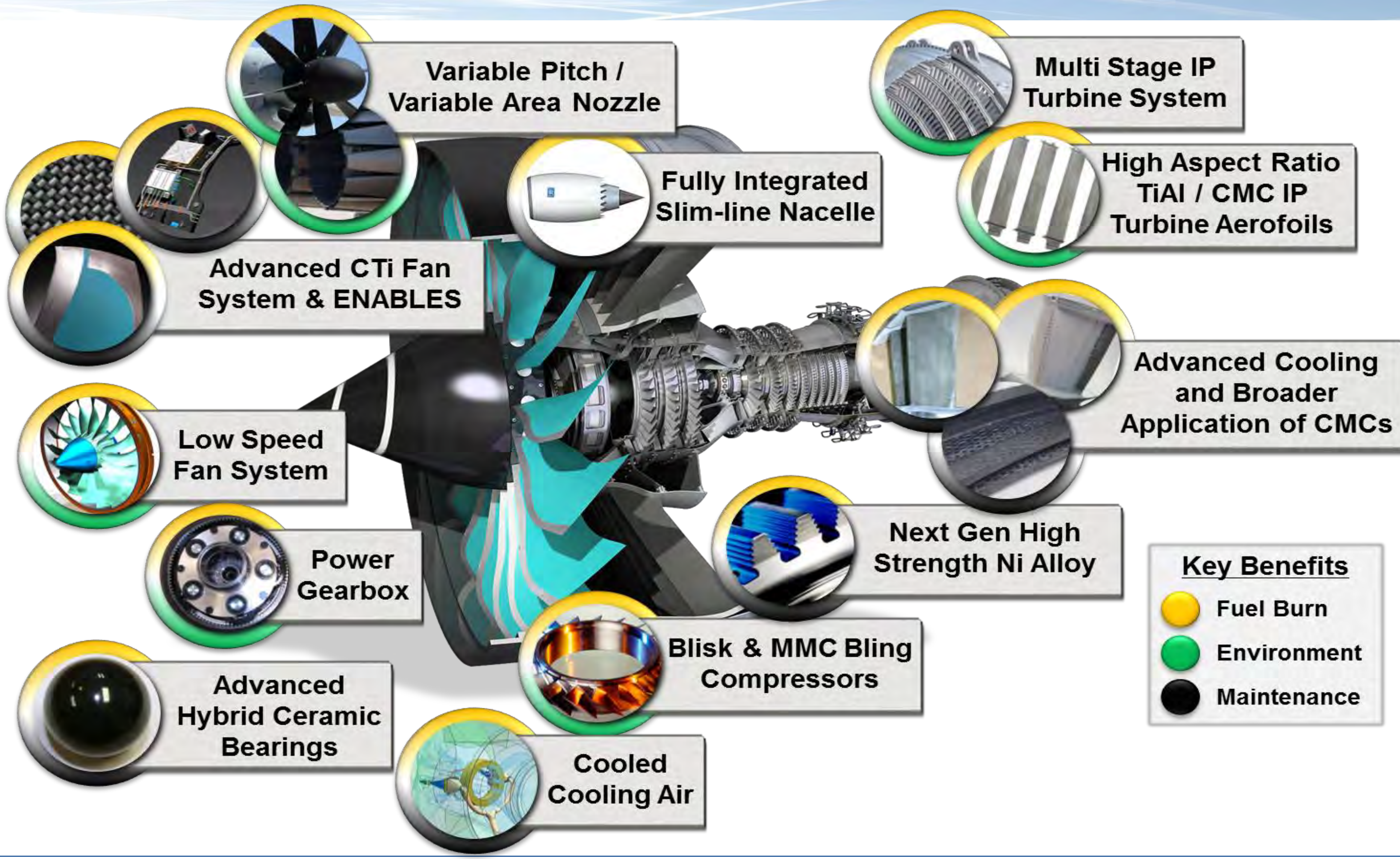
World-Leading Product Evolution

Trent XWB	Advance	UltraFan™ / Open Rotor
World's most efficient engine		
Integrated Propulsion System	Integrated Propulsion System	Integrated Slim Line Nacelle (No Thrust Reverser)
Lightweight LPT System	Lightweight LPT System	Geared Multi Stage IPT System
Hollow Ti Fan System	CTi Fan System	Variable Pitch CTi Fan System
3 Stage Turbine Core	Advance Core	Advance Core

Advance – Technology Advances



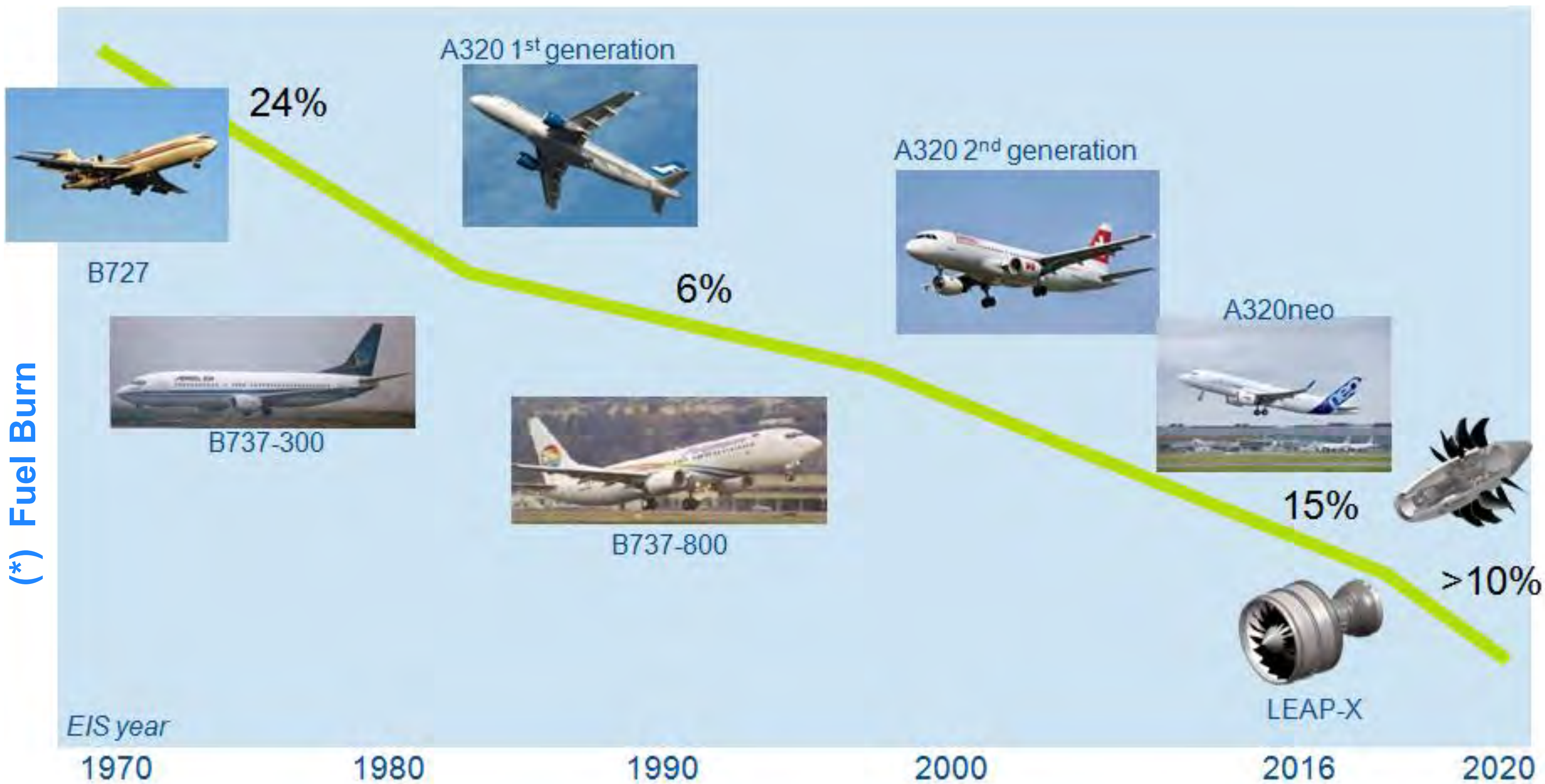
UltraFan – Technology Advances



Rolls-Royce

MITIGATION SOLUTIONS (SAFRAN-AE)

➔ **Continuous Effort on Technology to Reduce Fuel Burn and CO_2**



SAFRAN

MITIGATION SOLUTIONS (SAFRAN-AE)

➔ Exemple: CROR solution

- A Counter Rotating Open Rotor (CROR) is expected to provide a significant benefit in terms of FB/CO2 reduction, with an estimated reduction of -35% on a SMR aircraft, compared to 2000 technology.
- The development of this engine requires advanced solutions in terms of aerodynamics, acoustics and mechanics. It requires also a much stronger integration to the aircraft than usual turbofans.
- A demonstrator (pusher type) is developed in CS SAGE2 ITD under Safran-ae lead and should be tested beginning of 2017.

Open Rotor will run in the coming months on a brand new Safran Open Air Test Bench.

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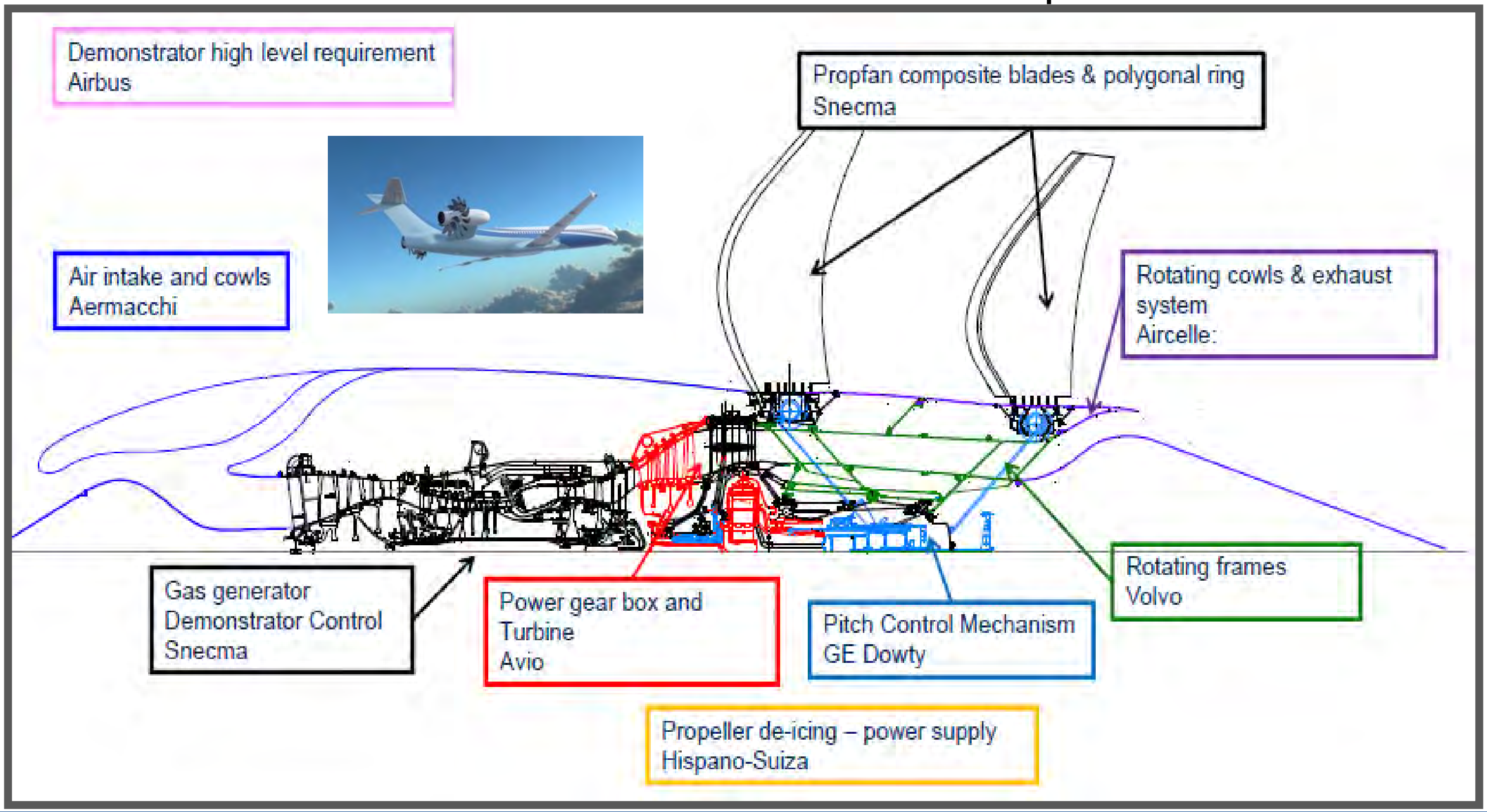
MITIGATION SOLUTIONS (SAFRAN-AE)

➔ Exemple: CROR solution

- Success of CROR is based on many new technologies: new components (high power counter-rotating gearbox, rotating frames…), adapted mouning system design, specific control system…
- Overview of demonstrator's bricks and breakdown with partners:



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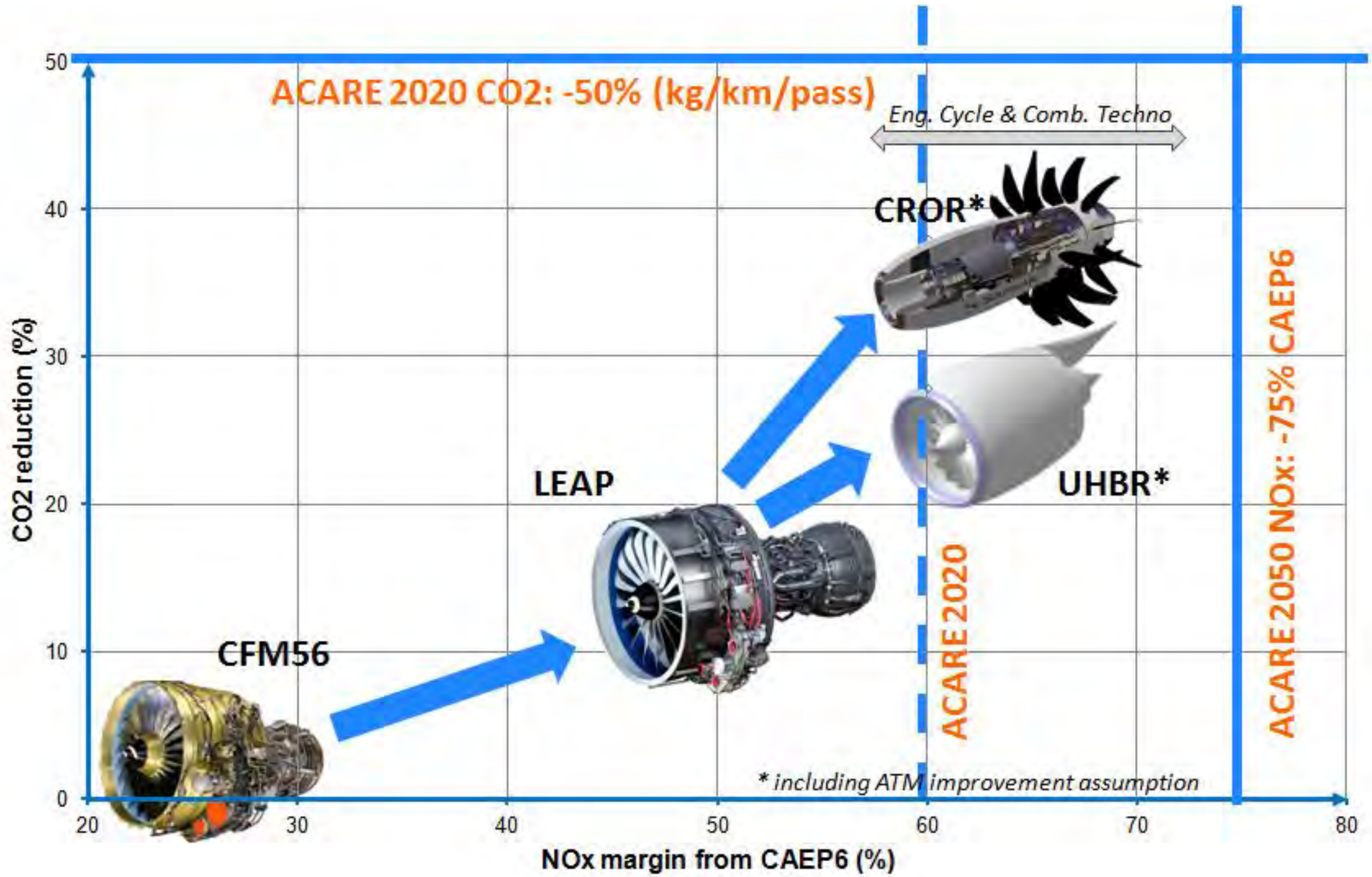
➔ Promising but more to be done



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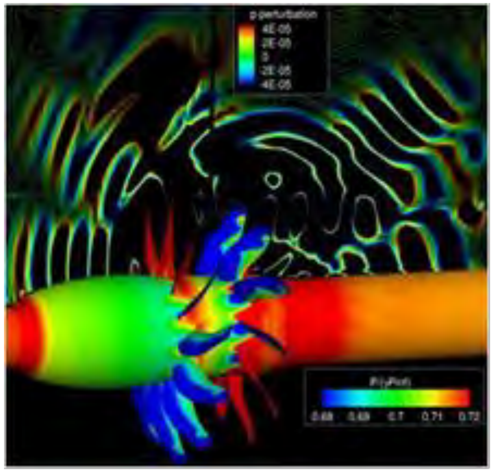
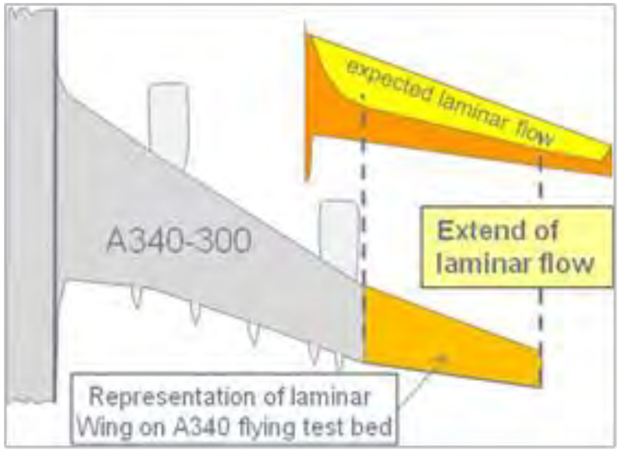
CO2 MITIGATION SOLUTIONS

- **ACARE 2050 very challenging CO_2 reduction objective would permit to mitigate substantially the effect of traffic growth.**
  - So, it is essential to pursue a tremendous effort at the aircraft level, the engine level and the ATM & flight operation level in order to progress towards this ambitious goal.

- **Unconventional configurations like aircrafts equipped with CROR concept or UHBPR concepts, must be further developed.**
  - Their mitigation potential, complemented with laminar wing benefit, must be maximised and their maturity must be pushed over TRL5

URANS CROR calculation





Laminar wing test bed

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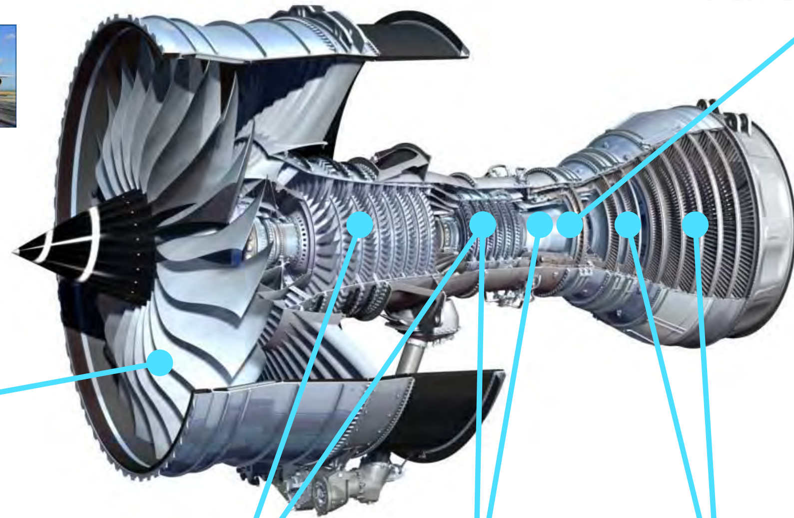
EU R&T Technology Programmes

Whole Engine Demonstration

Clean Sky 2

SAGE 6
Lean Burn Combustor
Clean Sky

Low NOx



Low Noise

Openair
Silencer
SAGE 1
Clean Sky

Dream
Enoval
+ Clean Sky 2

New engine Architectures

NEWAC
E-BREAK

LEMCOTEC
FIRST

FACTOR
ERIKA

Low CO_2

Rolls-Royce & FP7: **39 projects**

Rolls-Royce & Clean Sky:**4 major demonstrators**

Rolls-Royce

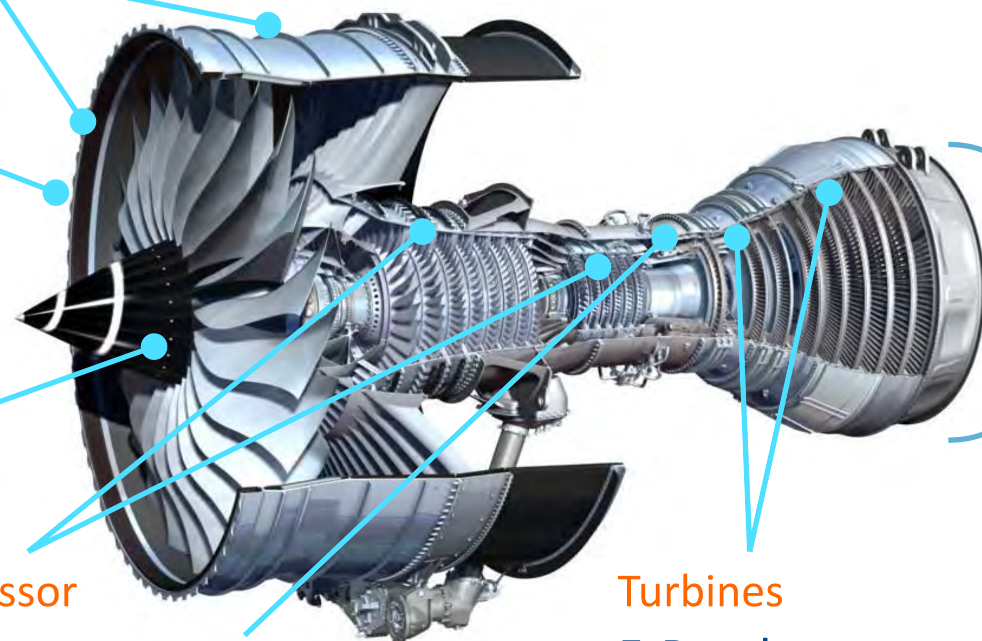
EU R&T Technology Programmes

Clean Sky

Clean Sky 2

Flight and Ground Test of Composite Systems

Flight and Ground Test of UltraFan™



Fan Noise
Openair
Dream
Flocon
Silencer

Engine Architecture
Dream
Enoval

Whole Engine Modelling
Crescendo

Oil & Seal Systems
Elubsys

Fan
Enoval

Compressor
Lemcotec
E-Break
NEWAC

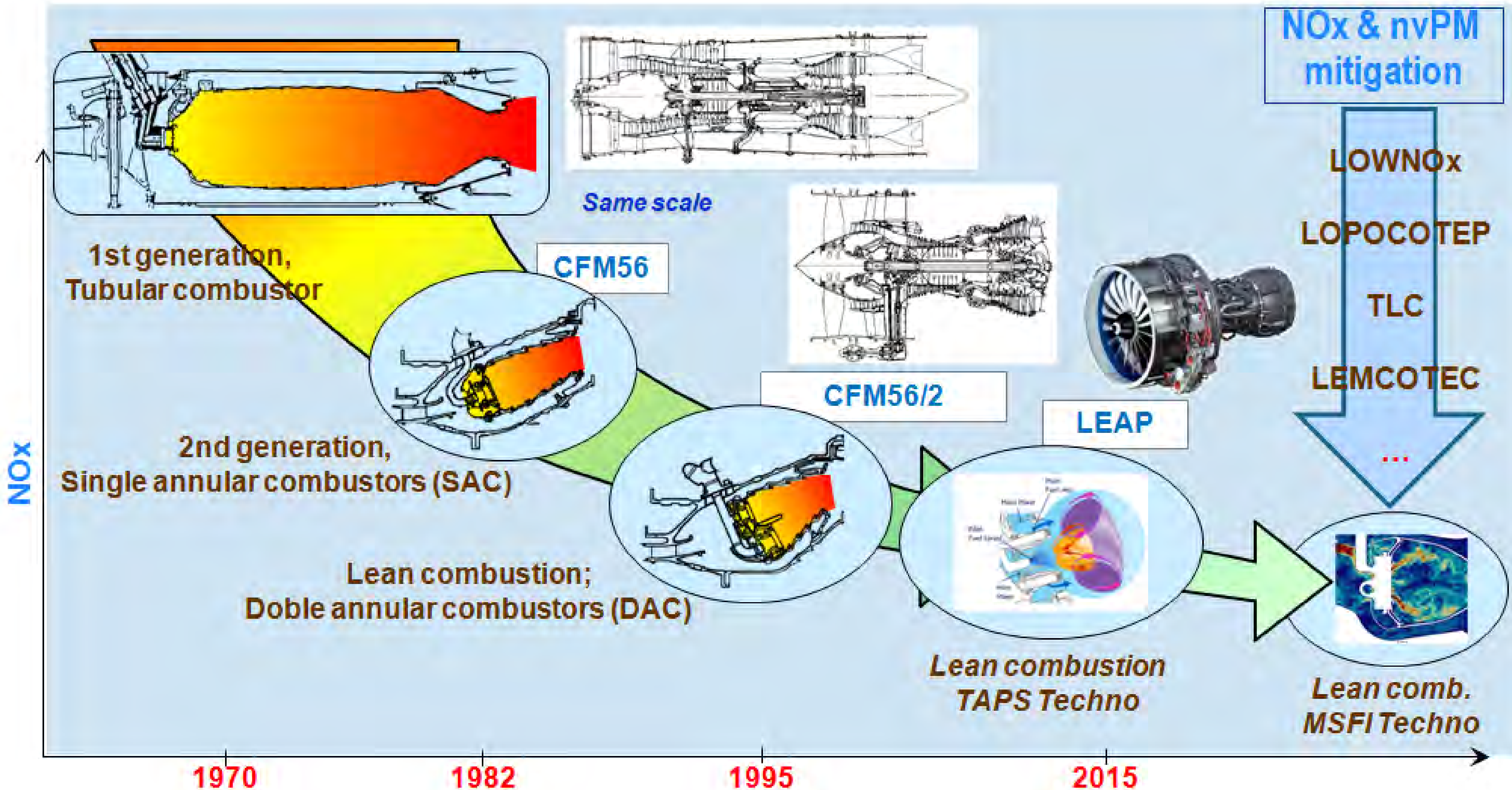
Combustor
Lemcotec
First, KIAI
EEFAE

Turbines
E-Break
Ericka
Factor
Future

Rolls-Royce

MITIGATION SOLUTIONS (SAFRAN-AE)

➔ **Continuous effort (on combustor techno) to reduce non-CO2 emissions**



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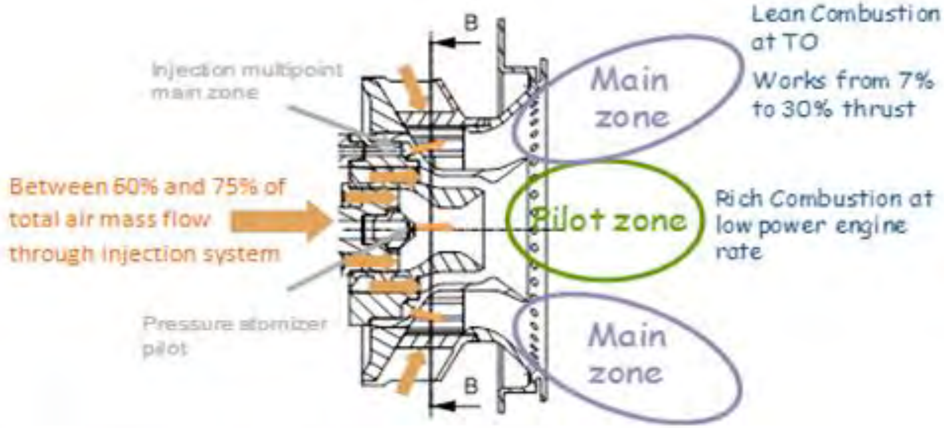
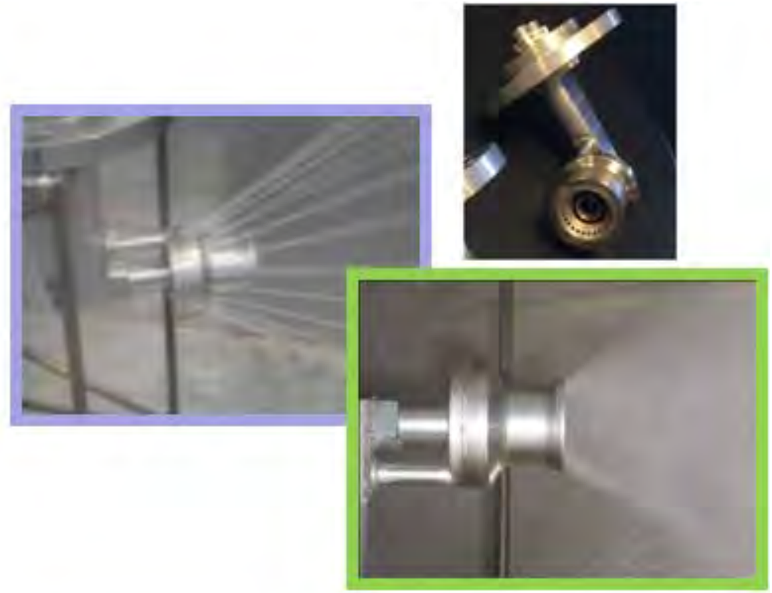
MITIGATION SOLUTIONS (SAFRAN-AE)

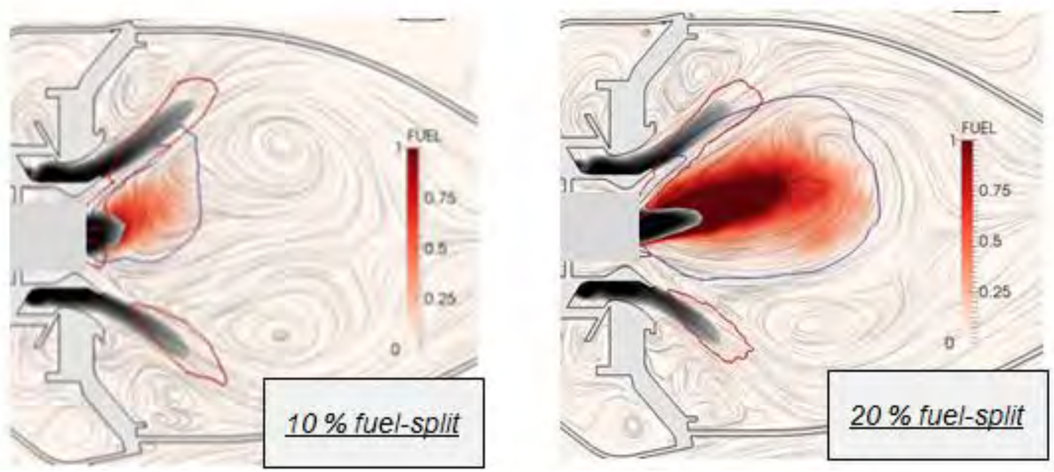
➔ NOx mitigation – MSFI Technology





- ➢ Safran-ae lean combustion technology is called MSFI (Multi Staged Fuel Injection)

- ➢ Optimisation of the fuel split between the pilot injector and the primary injector is supported by LES calculations (stronger interaction between pilot & lean flame is seen at 20% split)



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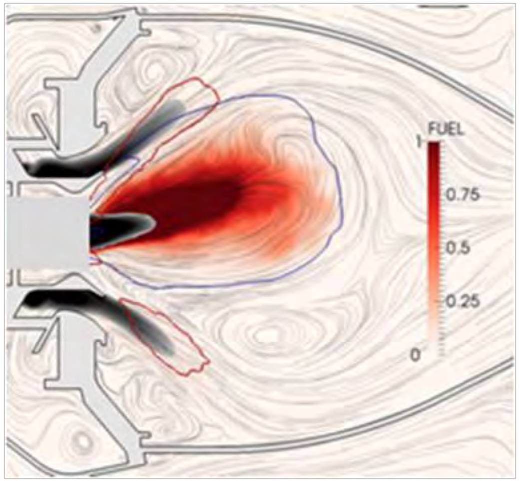
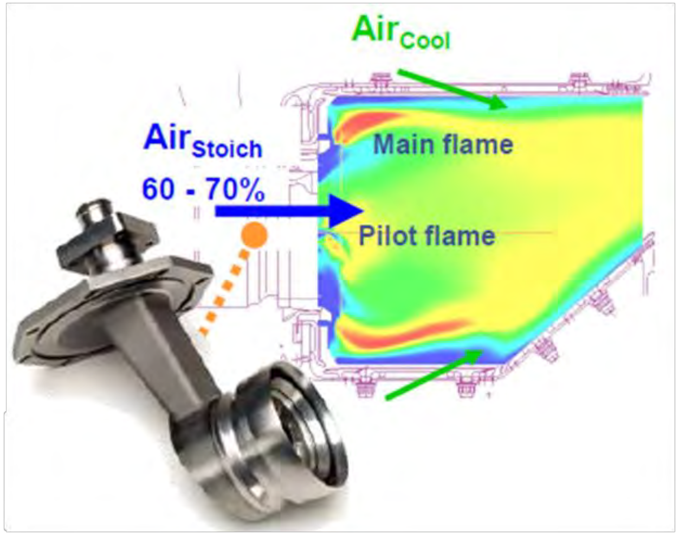
COMBUSTION EMISSIONS MITIGATION SOLUTIONS

Consensus appears that fine particles (nvPM) reduction must be also achieved, in addition to NOx. This induces critical R&T on:

➔ **The combustor technology itself in order to reduce both NOx & nvPM**

- enhanced lean combustion in general (achieving TRL6 maturity & extending its application to smaller size and/or smaller OPR engine combustors),
- focus on more specific aspects which may be beneficial to particles reduction





Lean combustion technology: Snecma calculation (left), Rolls-Royce solution (right)

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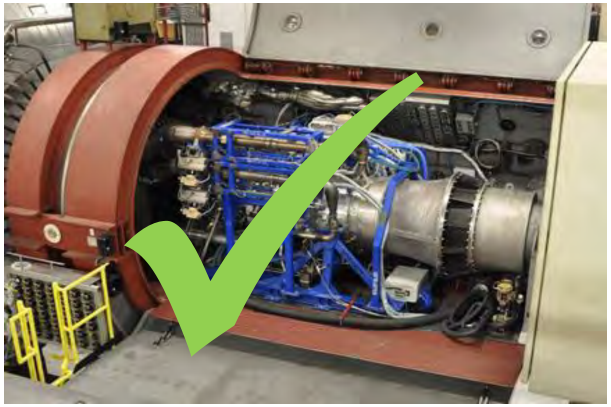
Rolls Royce Lean Burn Pre-Production Validation



E3E Core (operability)

EFE (Emissions and high T performance)

ALECSYS (Trent engine) System Commissioning

Stennis (Noise)

Manitoba (Icing)

Flying Test Bed (In-flight Operability)

Rolls-Royce

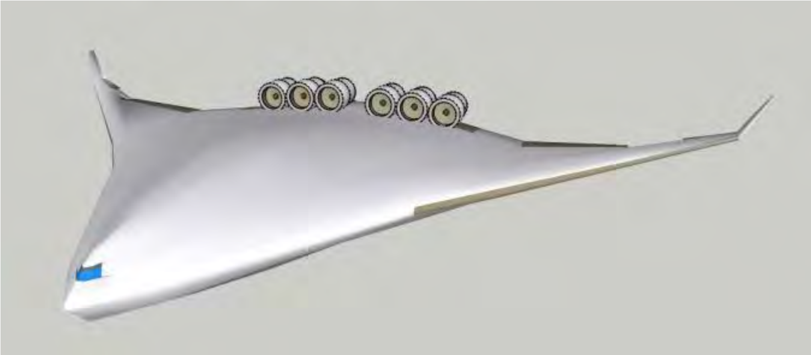
CO2 MITIGATION SOLUTIONS

- **Aircraft/Engine technologies must be further and continuously improved**
  - both for evolutionary aircraft/engine applications and longer term disruptive ones

- **More radically unconventional solutions (distributed propulsion a/c…) should be also considered for much longer term and at lower TRL**

Propulsive-Fuselage Concept (PFC)

Distributed Multiple-Fans Concept (DMFC)



DISPURSAL Project Analysis

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MITIGATION SOLUTIONS & RECOMMENDATIONS:

➔ Status against ACARE goals

	Reference 2000	ACARE 2020 Goals (at TRL6)		ACARE 2050 Goals (at TRL6)		FORUM-AE Assessment (2015) (extrapol. at TRL6 in 2020)
		High Level	detailed (SRA)	High Level	detailed (SRIA)	
CO_2	*Representative technology of aircraft & engine with 2000 EIS, & representative 2000 ATM*	"-50% per pass km"	aircraft: -20% to -25% engine: -15% to -20% ATM: -5% to -10%	"-75% per pass km"	aircraft & engine: -68% ATM: -12% Other: -12%	**aircraft + engine +ATM: ≈ -38% in average per pass km**
NOx (LTO)		"-80%"	engine: -60% CAEP6 ; complement achieved by aircraft + ATM	"-90%"	engine: -75% CAEP6 ; complement achieved by aircraft + ATM	**engine: [-55%, -65%] CAEP6**
NOx (Cruise)		"-80%"	Achieved through -50% Fuel Burn & -60% cruise EINOx reduction	"-90%"	Achieved through -75% Fuel Burn & further cruise EINOx reduction	not quantified
Other emissions		"damaging emissions reduced"	emissions qualitatively reduced (particles, CO, UHC) and better understanding of impacts	"emissions-free taxiing" + qualitative reduction	knowlegde of emissions (particles, VOC) and better understanding of impacts	better knowledge of engines particles emissions

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MITIGATION SOLUTIONS CONCLUSIONS

- Engine manufacturers spend vast amounts of money on emissions reductions.
- Support from States and EU is critical to success of these programmes. Manufacturers match any funding with their own funding.
- Airframers expect new engine concepts to be fully tested to high technology readiness level before they will accept them on to new aircraft.
  - There are many engine demonstrator programmes for both CO2 and combustion emissions (e.g. NOx reductions) on going and these will define the future aircraft.
- The ACARE targets and Flight Path 2050 targets are extremely challenging but manufacturing industry is fully committed to improving the technology towards those targets.

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BACK-UP

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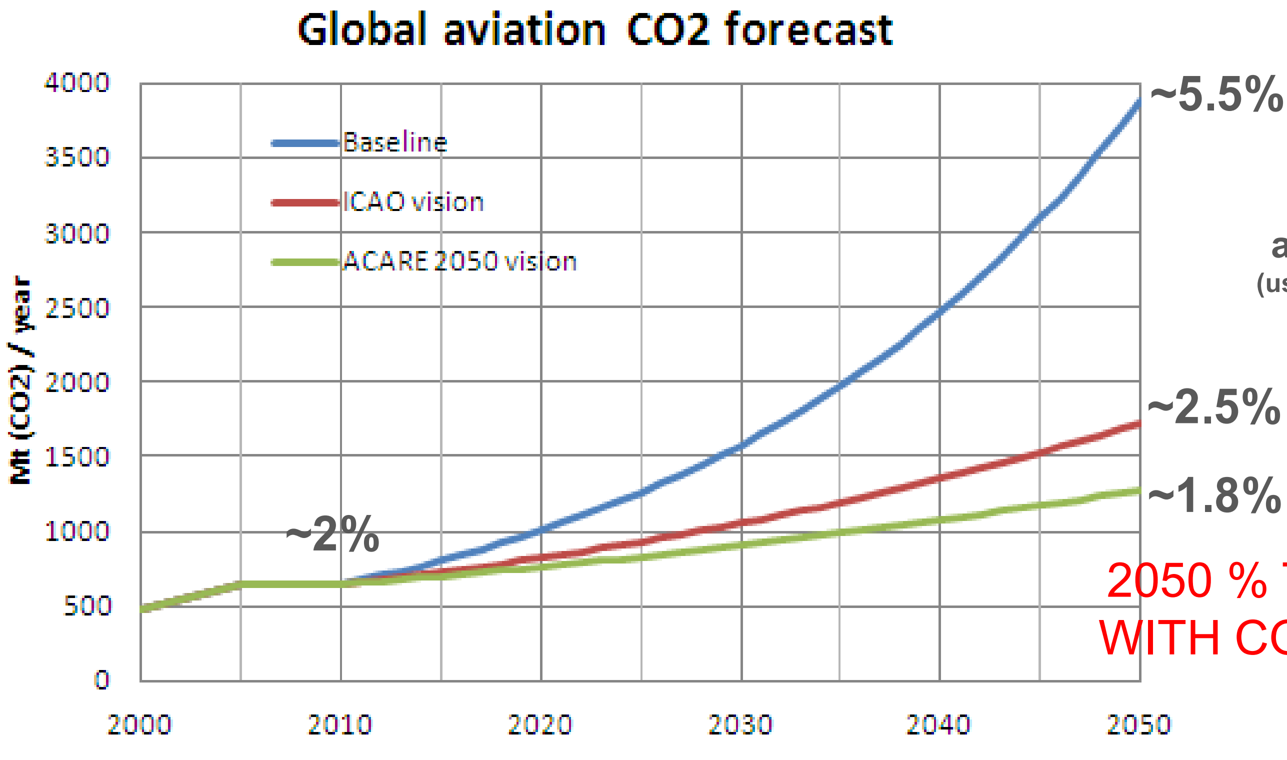
CONTEXT: TRAFIC GROWTH & AVIATION EFFICIENCY

➔ Evolution of Anthropogenic CO2 from aviation?



~x% = % of anthropogenic CO2 (using GCP 2014 estimations)

2050 % TO BE UP-DATED WITH COP21 ASSUMTION

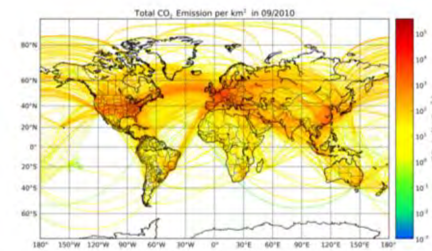
Global aviation CO2 forecast

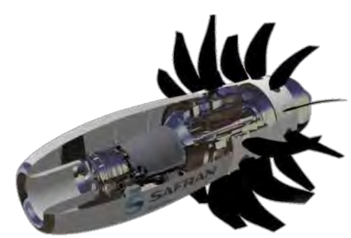
assumptions: ACARE 2050 goal is achieved in 2050 and fully introduced in the 2050 fleet ; there is a continuous improvement of average efficiency from now to 2050 ; ICAO 37th Assembly projected average air traffic growth of 4.6% is taken

MONITORING[A]

➔ Very large number of relevant projects

PROJECT	T0	STATUS	Coordinator	TITLE	TYPE
REACT4C	2010	Completed	DLR*	Reducing Emissions from Aviation by Changing Trajectories for the Benefit of Climate	Impacts
ECATS	2005	Foundation	ECATS*	Environmental Compatible Air Transport System => Foundation	Impacts
MOZAIC	1994	On-going	RC Jülich	Measurement of Ozone, Water Vapor, Carbon Monoxide, Nitrogen Oxide by Airbus In-Service Aircraft	Impacts
IAGOS	2008	On-going	RC Jülich	In service Aircraft for a Global Observing System	Impacts
IAGOS ERI	2009	On-going	RC Jülich	In service Aircraft for a Global Observing System / European Research Infrastructure	Impacts
CARIBIC	2004	On-going	MPI Chemie, Mainz	Civil aircraft for the regular investigation of the atmosphere based on an instrument container	Impacts
QUANTIFY	2005	Completed	DLR*	Quantifying the Climate Impact of Global and European Transport Systems	Impacts
CleanSky - SFWA	2008	On-going	AI*	SMART Fixed Wing Aircraft	Aircraft
CleanSky - GRA	2008	On-going	Alenia	The Green Regional Aircraft	Aircraft
CleanSky - GRC	2008	On-going	Eurocopter	Green Rotorcraft	Aircraft
NACRE	2005	Completed	AI*	New Aircraft Concepts Research	Aircraft
AHEAD	2011	On-going	TU Delft	Advanced Hybrid Engines for Aircraft Development	Aircraft
DISPURSAL	2013	On-going	Bauhaus	Distributed Propulsion and Ultra-high By-pass Rotor Study at Aircraft Level	Aircraft
CleanSky - SAGE	2008	On-going	RR*&SN*	Sustainable And Green Engine	Engine
DREAM	2008	Completed	RR*	valiDation of Radical Engine Architecture systeMs	Engine & Fuel
NEWAC	2006	Completed	MTU	NEW Aero engine Core concepts	Engine HP
VITAL	2005	Completed	SN*	Environmentally Friendly Aero-Engine	Engine BP
LEMCOTEC	2011	On-going	RRD*	Low Emissions Core-Engine Technologies	Engine BP
EBREAK	2012	On-going	TM*	Engine Breakthrough components and subsystems	Engine
ENOVAL	2013	On-going	MTU	The Engine mOdule Validators	Engine BP





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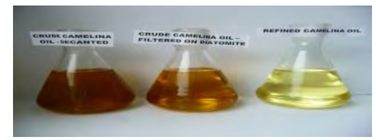
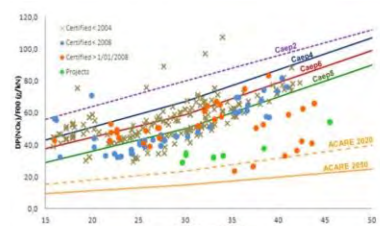
MONITORING[B]

➔ Monitoring activity (continued)

KIAI	2009	Completed	SN*	Knowledge for Ignition, Acoustics and Instabilities	Combustor
FIRST	2010	On-going	RR*	Fuel injection research	Combustor
FACTOR	2010	On-going	SN*	Turbine combustor interaction	Combustor
IMPACT-AE	2011	On-going	RRD*	Design methodologies	Combustor
TECC-AE	2008	Completed	SN*	Technology Enhancements for Clean Combustion	Combustor
INTELLECT D.M.	2003	Completed	RRD*	Integrated Lean Low-Emission Combustor Design Methodology	Combustor
TIMECOP-AE	2006	Completed	TM*	Toward Innovative Methods for Combustion Prediction in Aero-engines	Combustor
TLC	2005	Completed	SN*	Towards Lean Combustion	Combustor
LOPOCOTEP	2000	Completed	SN*	LOw POllutant COmbustor TEchnology Project	Combustor
ALFA-BIRD	2008	Completed	Eu-Vri	Alternative Fuels and Biofuels for Aircraft Development	Fuel
SWAFEA	2009	Completed	Onera	Sustainable Way for Alternative Fuels and Energy in Aviation	Fuel
burnFAIR	2010	On-going	LH*	Searching for a viable kerosene replacement	Fuel
ITAKA	2012	On-going	SEN*	Initiative Towars sustAinable Kerosene for Aviation	Fuel
SESAR	2007	On-going	JU	Single European Sky ATM Research	Operations
CleanSky - SGO	2008	On-going	Thales	System for Green Operation	Operations
AIRE	2009	On-going	SJU-FAA	Atlantic Interoperability Initiative to Reduce Emissions	Operations
ERAT	2007	Completed	To70	Environmental Responsible Air Transport	Operations
CS-EcoDesign	2008	On-going	DA&FHF	Eco-Design (co-leaded by Dassault & Fraunhofer)	Recyclability
CleanSky - TE	2008	On-going	Thales	Technology Evaluator	Assessment
AERONET III	2003	Completed	DLR*	Aircraft Emissions and Reduction Technologies	Network & monitoring
X-NOISE EV	2010	On-going	SN*	Aviation Noise Research Network and Coordination	Network & monitoring for NOISE
COREJet-fuel	2013	On-going	FNR	Coordinating research and innovation of jet and other sustainable aviation fuel	Network & monitoring for Fuel
Team-Play	2010	Completed	DLR*	Tool Suite for Environmental and Economic Aviation Modelling for Policy Analysis	Regulation
NEPAIR	2003	Completed	Qinetiq	Development of the technical basis for a New Emissions Parameter covering the whole AIRcraft	Regulation
GreenAir	2009	On-going	EADS	Generation of Hydrogen by Kerosene Reforming via Efficient and Low-Emission New Alternative, Innovative, Refined Technologies for Aircraft Application	Others





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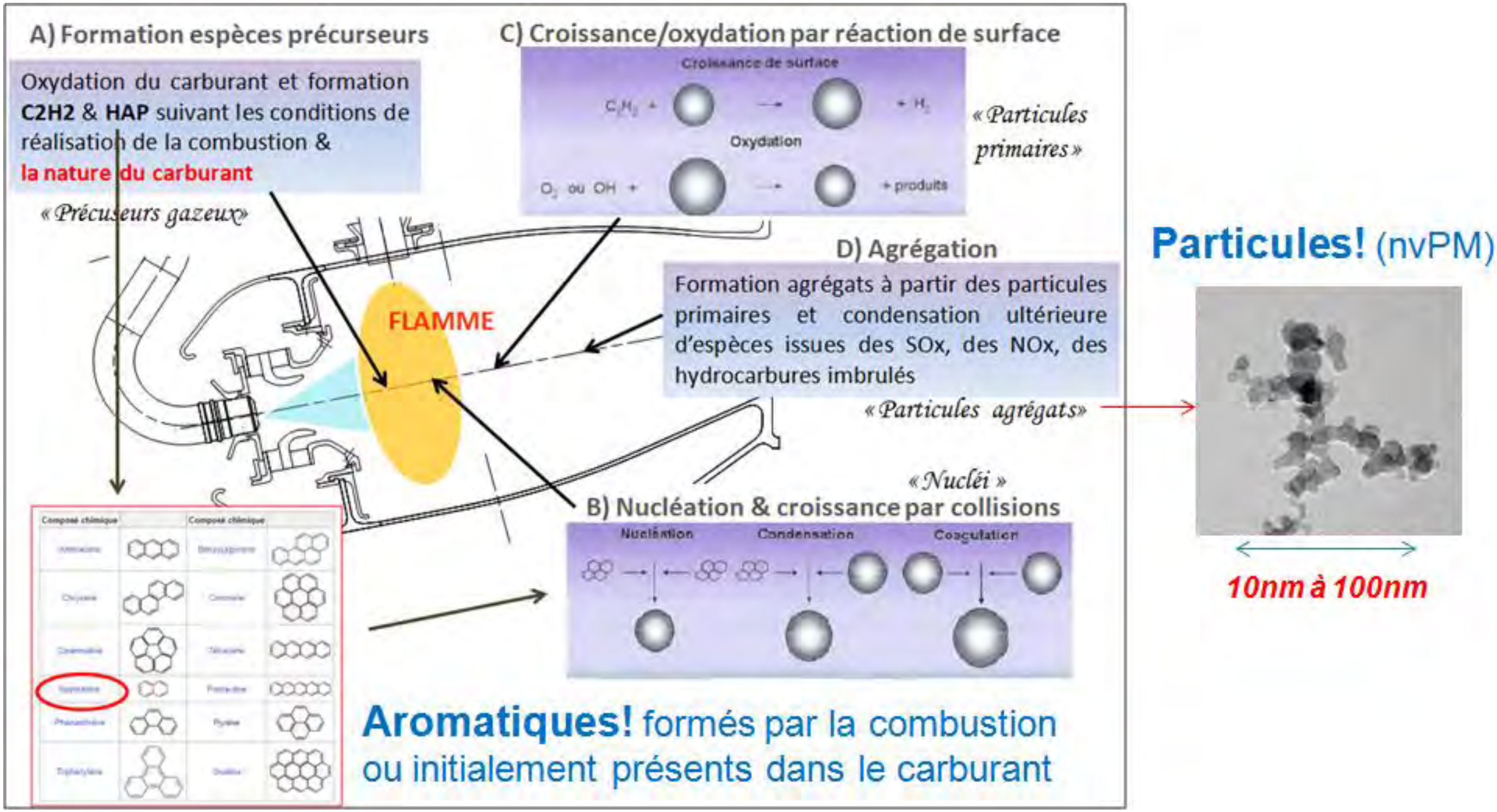
MITIGATION SOLUTIONS (SAFRAN-AE)

➔ nvPM mitigation – RQL technology



SAFRAN

World-leading product evolution

Trent XWB

World's most efficient engine

Advance

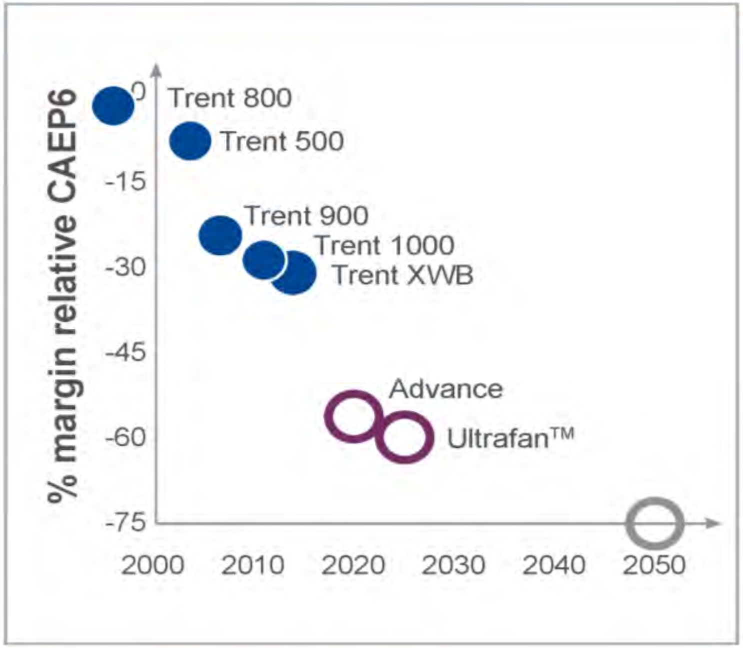
UltraFan™ / Open Rotor

- Drives a high pressure ratio core via 3 stages of turbines (1 HP, 2 IP)

- Redistributes workload between the IP and HP compressors and turbines

- An enhanced IP turbine drives the fan via a power gearbox, allowing deletion of the LP turbine

NOx (Engine)



ACARE goal -90%
NOx overall reduction:

- -75% Rolls-Royce contribution
- -15% from operational efficiency improvements

Trent family Technology demonstrator engine targets

ACARE (Advisory Council for Aviation Research and Innovation in Europe) Flightpath 2050 target

Rolls Royce Lean Burn Combustion System Architecture